

Effect of the CO₂ Milliwatt Laser on Tensile Strength of Microsutures

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Background and Objective: Laser-assisted tissue repair is often accompanied by a high dehiscence rate, which may be due to alterations in suture material after laser exposure. The goal of this study was to investigate the effect of CO₂ laser irradiation on the tensile strength of microsurgical suture material.

Study Design/Materials and Methods: 10-0 nylon and 25 μ m stainless steel threads were exposed to 12 combinations of power densities (62, 124, and 186 W/cm²) and pulse durations (0.5, 1, 2, 3 s) and tested on a tensometer for their tensile strength.

Results: At power densities of 186 W/cm², the 10-0 nylon thread disrupted during laser irradiation, regardless of pulse duration. This was also the case at power densities of 124 W/cm² for 2 s and 3 s pulse duration. At 124 W/cm² for 0.5 and 1 s, the tensile strength decreased with 70% relative to the control. At 62 W/cm², the tensile strength gradually decreased from 100% (0.5 s pulse duration) to 50% (3 s pulse duration) relative to control. Stainless steel thread resisted all laser irradiations.

Conclusions: The 10-0 nylon thread is significantly compromised by irradiation with the CO₂ milliwatt laser and therefore meticulous care should be taken not to irradiate the sutures during laser tissue welding. *Lasers Surg Med* 20:64–68, 1997.

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Key words: laser microsurgery; 10-0 nylon; steel wire; surgical thread; tissue welding

INTRODUCTION

Microsurgical laser tissue fusion is currently the subject of intensive investigations in various fields of surgery. Despite many progresses achieved, laser tissue fusion still needs additional stay sutures to provide the initial strength for holding the tissues together. Most commonly, 10-0 nylon sutures are used for supporting the laser welds in microsurgical laser repair of arteries [1–3], veins [4], nerves [5–7], vas deferens [8, 9], and urethra [10,11].

Due to its desirable properties of low tissue penetration and limited spread in tissue, the CO₂ laser ($\lambda = 10.6 \mu$ m) is currently the most frequently laser used for microsurgical tissue fusion. As the CO₂ laser energy is mostly absorbed at the tissue surface, it also may certainly affect the suture material with regard to its tensile strength when occasionally irradiated. The consequences of altered tensile strength of the sutures could be

disastrous for the patency and bonding rate of the fused tissues. Because no data are available on the effect of CO₂ laser irradiation on microsurgical suture material, this study was designed to investigate the tensile strength of 10-0 nylon thread irradiated by a CO₂ laser at different power densities and exposure times. As a possible (future) alternative to nylon thread, we also investigated the tensile strength of 25- μ m stainless steel thread, both laser irradiated and nonirradiated.

MATERIALS AND METHODS

Two different suture threads were used in this study: 10-0 monofilament nylon thread (Der-

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TABLE 1. Effect of CO₂ Laser Light Doses on the Tensile Strength in Newton (mean \pm sd) of 10-0 Nylon Suture Thread

Power density (W/cm ²)	Pulse duration (s)				
	0	0.5	1	2	3
0	0.35 \pm 0.02	—	—	—	—
62	—	0.34 \pm 0.03	0.31 \pm 0.05	0.24 \pm 0.05	0.18 \pm 0.12
124	—	0.08 \pm 0.05 ^a	0.12 \pm 0.02 ^a	_b	_b
186	—	_b	_b	_b	_b

^aOne suture disrupted during laser irradiation.

^bAll sutures disrupted during laser irradiation.

malon black monofilament, Davis-Geck, Hampshire, U.K.), and 25- μ m soft stainless steel thread (Trakus, Bergneustadt, Germany). The suture material (\pm 5 cm each) was stretched on a piece of cork and single pulse laser irradiation of the thread was performed at 12 different laser settings (power densities of 62, 124, and 186 W/cm²; pulse duration of 0.5, 1, 2, and 3 s). During irradiation, the thread was positioned in the middle of the laser beam. Six irradiations were performed for each group of laser settings. Nonirradiated thread ($n = 6$) served as a control.

For all procedures, a CO₂ laser (Cooper LS 860, Cooper LaserSonics, Santa Clara, CA) was used in conjunction with an operating microscope at 40-fold magnification (OpMi-1, Zeiss, Jena, Germany) and a joystick micromanipulator (Cooper LaserSonics LS-11). The laser was operated in a cw mode using an electrical shutter (T 132, Optilas, Eindhoven, The Netherlands) with a foot switch to control the pulse duration. A spot size of 320 μ m was used, with powers of 50, 100, and 150 mW (power densities of 62, 124, and 186 W/cm²). All procedures were carried out by the same person.

The tensile strength of the threads was measured directly after the irradiation using a tensometer (TM type W, Monsanto, U.K.), coupled to a motor pulley (Hoover MK IV, U.K.) and a x-y plotter. The threads were strained at a rate of 3.18 mm/min, until breakage occurred. The force (in Newton, N) to do so was recorded as the tensile strength. The data were statistically analyzed using a Student t-test.

RESULTS

The tensile strength of the nonirradiated group was 0.35 \pm 0.02 N. Irradiation at power densities of 186 W/cm² resulted in disruption of the nylon thread, regardless of the pulse duration. Thus no tensile strength could be recorded for these groups. Also, at power densities of 124

W/cm², disruption of the nylon thread occurred with pulse duration of 2 s and 3 s. Irradiation at 124 W/cm² for 0.5 s and 1 s resulted in a decrease of the tensile strength with a factor of 3 to 4. At power densities of 62 W/cm², the tensile strength of the nylon thread was not altered at 0.5 s and gradually decreased with irradiations at 1 s, 2 s, and 3 s pulse duration. These values were significantly lower than the control group ($P < 0.01$). Table 1 gives an overview of the tensile strength data for the 10-0 nylon thread. The relation of the relative strength loss at different power densities and pulse durations is shown in Figure 1. Figure 2 shows the relative strength loss at identical total doses of energy at different pulse durations.

The tensile strength of nonirradiated stainless steel thread was 0.55 \pm 0.03 N (mean \pm sd), which was statistically different from the 10-0 nylon control group ($P < 0.01$). Laser irradiation of the steel thread did not alter its tensile strength, not even at power densities of 186 W/cm² for 3 s pulse duration.

DISCUSSION

Tissue fusion by laser energy has certain advantages over conventional suture repair such as less traumatic tissue handling, avoidance of a foreign body reaction, a watertight sealing of the tissues, and a reduced operation time [1,9,10,12]. The mechanism of CO₂ laser tissue welding is attributed to protein denaturation [12, 13] and/or fusion of collagen [14, 15]. However, the major disadvantage of tissue fusion by laser is the weak bonding strength. Even with the use of additional stay sutures, the bonding rate is still not optimal, which is, e.g., the case for laser nerve repair [16, 17].

When dealing with nerve repair, the nerve ends will, after transection, retract due to the elasticity of the nerve. Therefore, the end-to-end nerve repair is always under some degree of ten-

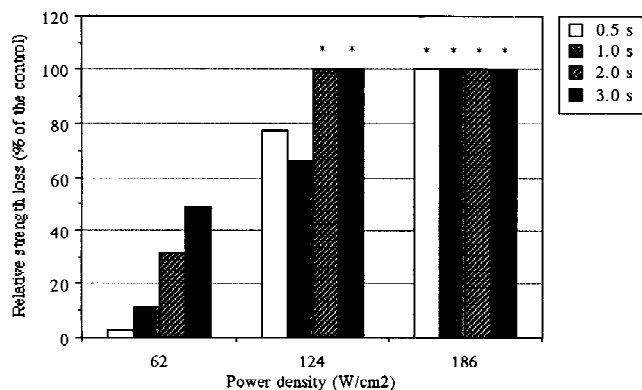


Fig. 1. Relative strength loss of the nylon suture as a function of the power density at different pulse durations. An asterisk (*) signifies that the thread disrupted during irradiation (100% loss of strength).

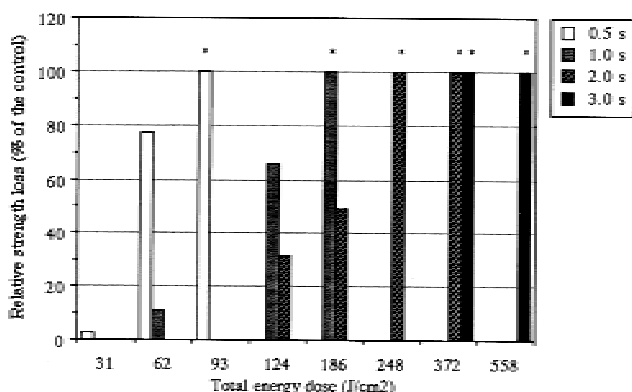


Fig. 2. Relative strength loss of the nylon suture at identical total light doses at different pulse durations. An asterisk (*) signifies that the thread disrupted during irradiation (100% loss of strength).

sion, which will vary with the degree of elasticity of the nerve and with the position of the surrounding joints. In CO₂ laser nerve repair, one or two stay sutures are usually placed in the epineurium (for easy handling and approximation) and subsequent laser irradiation follows of the nerve [5–7]. Still, the dehiscence rate varied from 40% to 87% [16–18]. However, in experiments performed in the same nerve model (sciatic nerve in the rat), nerve repair with one or two sutures without laser irradiation resulted in a dehiscence rate of 0% [19, 20]. This finding in the literature and our own pilot experiments (unpub. obs.), in which we found dehiscence of the laser welded nerves even with the use of three stay sutures, led us to the hypothesis that the tensile strength of suture material could be altered by laser irradiation, resulting in bonding failure.

There are only two studies that report on the effect of laser irradiation on the tensile strength of sutures. In the first study the laser used was the diode laser ($\lambda = 808$ nm) [21], which is not (yet) commonly used for tissue welding, and the size of the sutures investigated varied from 3-0 to 6-0. These sutures are of little use for microsurgical repair of tissues. In the second study, the laser utilized was a KTP laser (532 nm) and the sutures investigated were 4-0 Daxon etc. [22]. We have selected the CO₂ laser and 10-0 nylon thread (which has a diameter of 25 μ m) for this study, as these are most commonly used for microsurgical laser repair of arteries, veins, and nerves. The laser settings investigated (power densities = 62, 124, and 186 W/cm², pulse duration = 0.5, 1 s, 2 s, and 3 s) represent the generally used parameters for tissue welding. Moreover, the selected laser settings have been shown to produce strong welds in our previous study of nerve welding [23]. Irradiation with the CO₂ laser at 186 W/cm² resulted in suture disruption regardless of the pulse duration. Disruption of the sutures also occurred at 124 W/cm² for 2.0 s and 3.0 s. At power densities of 124 W/cm² for less than 2.0 s pulse duration and at 62 W/cm² for 1 s, 2 s, and 3 s pulse duration, the mean tensile strength was significantly less than that of the control group ($P < 0.01$). Although it is obvious that disruption of the suture thread occurs at high CO₂ laser powers, it is surprising that it also occurs at the very low powers, as the effects on tissue by irradiation with low power CO₂ laser are only microscopically visible. These results suggest that irradiation of the nylon sutures with a low power CO₂ laser impairs the tensile strength of the repair, which may result in early wound dehiscence. It is likely that other surgical threads (Vicryl, polypropylene) also will be influenced by laser irradiation, as well as surgical threads larger than 10-0.

The suture material used in this study was dry. During surgery, the thread will become wet after contact with tissue, and it is likely that the energy absorption of the laser will be altered. However, our pilot experiments showed that there was almost no difference in tensile strength of dry and wet nylon thread after laser irradiation. Moreover, tissue welding with the CO₂ laser is successful only when performed in a dry operative field. As the CO₂ laser is used clinically for welding of the vas deference [9, 24] and vessels [25] and in general for many other surgical procedures, meticulous care should be taken to avoid irradiation of the surgical thread. The appearance

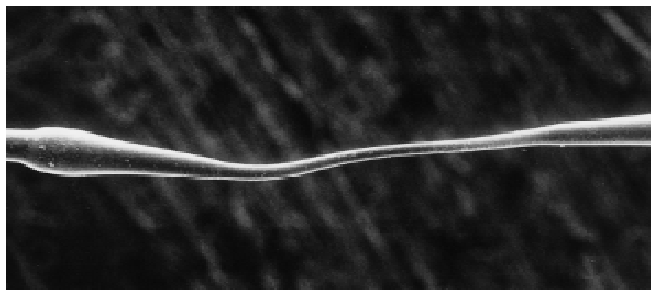


Fig. 3. Scanning electron micrograph of 10-0 monofilament nylon thread following CO₂ laser irradiation at 124 W/cm² for 0.5 s ($\times 190$). Note the narrowing and nearly disruption of the thread.

of irradiated 10-0 nylon thread (124 W/cm², 0.5 s) is seen in Figure 3.

As an alternative to nylon sutures, we have used 25 μ m soft stainless steel thread, which has the same diameter as 10-0 nylon. The use of stainless steel as suture material is known since the beginning of this century. However, the practical use of stainless steel wire is limited to orthopaedic and plastic surgery for fixation of bones. The use of stainless steel thread for microsurgical repair of nerves or vessels has never gained favor because of the kinking of the wire and its difficult manipulation like knotting [26, 27]. The mean tensile strength of the steel thread was 0.55 ± 0.03 N, which is statistically different from 10-0 nylon thread ($P < 0.01$). Irradiation of the steel thread with the CO₂ laser did not affect the tensile strength, regardless of the power density or pulse duration used. This means that the steel thread, from the point of safety, can be used in combination with laser welding without impairing the bonding strength of the repair site. Furthermore, stainless steel sutures have been shown to produce less amount of foreign body reaction than nylon sutures, which can be another potential advantage [28–30]. However, the feasibility of using stainless steel for neural repair in combination with laser welding has to be explored in *in vivo* studies.

In conclusion, we have demonstrated that (1) irradiation of 10-0 nylon thread with a low power CO₂ laser results in disruption of the thread or reduction of the tensile strength, (2) stainless steel thread has a greater tensile strength than 10-0 nylon thread, and (3) irradiation of stainless steel thread with a CO₂ laser does not alter its tensile strength. Further research in tissue welding using stainless steel as suture material is warranted.

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REFERENCES

1. Neblett CH, Thomsen SL, Morris JM. Laser-assisted microsurgical anastomosis. *Neurosurgery* 1986; 19:914–932.
2. Ruiz RA, Branfman GS, Lan M, Cohen BE. Laser-assisted microsurgical anastomoses in traumatized blood vessels. *J Reconstr Microsurg* 1990; 6:55–59.
3. Samonte BR, Fried MP. Laser-assisted microvascular anastomosis using CO₂ and KTP/532 lasers. *Lasers Surg Med* 1991; 11:511–516.
4. Abramson DL, Shaw WW, Kamat BR, Harper A, Rosenberg CR. Laser-assisted venous anastomosis: A comparison study. *J Reconstr Microsurg* 1991; 7:199–203.
5. Beggs JL, Fischer DW, Shetter AG. Comparative study of rat sciatic nerve microepineurial anastomoses made with carbon dioxide laser and suture techniques: Part 2. A morphometric analysis of myelinated nerve fibers. *Neurosurgery* 1986; 18:266–269.
6. Benke TA, Clark JW, Wisoff PJ, Schneider S, Balasubramaniam C, Hawkins HK, Laurent J, Perling L, Shehab A. Comparative study of suture and laser-assisted anastomoses in rat sciatic nerves. *Lasers Surg Med* 1989; 9:602–615.
7. Huang TC, Blanks RH, Crumley RL. Laser-assisted nerve repair. Laser-trimming of nerve ends with epineurial suture anastomosis. *Arch Otolaryngol Head Neck Surg* 1992; 118:277–280.
8. Krisch EB, Seidmon EJ, Samaha AJ, Phillips SJ, Tang CK, Shea FJ. Carbon dioxide milliwatt laser in the vasovasostomy of vas deferens in dogs: Part I. *Lasers Surg Med* 1990; 10:328–333.
9. Rosenberg SK, Elson LM, Nathan LJ. Laser vasovasostomy. A comparative retrospective study, using bioquantum microsurgical carbon dioxide laser. *Urology* 1988; 31:237–239.
10. Poppas DP, Schlossberg SM, Richmond IL, Gilbert DA, Devine CJ. Laser welding in urethral surgery: improved results with a protein solder. *J Urol* 1988; 139:415–417.
11. Poppas DP, Rooke CT, Schlossberg SM. Optimal parameters for CO₂ laser reconstruction of urethral tissue using a protein solder. *J Urol* 1992; 148:220–224.
12. Dew DK, Supik L, Darrow C2, Price GF. Tissue repair using lasers: a review. *Orthopedics* 1993; 16:581–587.
13. Okada M, Shimizu K, Ikuta H, Horii H, Nakamura K. An alternative method of vascular anastomosis by laser: experimental and clinical study. *Lasers Surg Med* 1987; 7:240–248.
14. Godlewski G, Rouy S, Dauzat M. Ultrastructural study of arterial wall repair after Argon laser micro-anastomosis. *Laser Surg Med* 1987; 7:258–262.
15. White RA, Kopchok GE, Donayre CE, Peng SK, Fujitani RM, White GH, Uitto J. Mechanism of tissue fusion in argon laser-welded vein-artery anastomoses. *Lasers Surg Med* 1988; 8:83–89.
16. Huang TC, Blanks RH, Berns MW, Crumley RL. Laser

- vs. suture nerve anastomosis. *Otolaryngol Head Neck Surg* 1992; 107:14–20.
17. Korff M, Bent SW, Havig MT, Schwaber MK, Ossoff RH, Zeale DL. An investigation of the potential for laser nerve welding. *Otolaryngol Head Neck Surg* 1992; 106: 345–350.
18. Fischer DW, Beggs JL, Kenshalo DL, Shetter AG. Comparative study of microepineurial anastomoses with the use of CO₂ laser and suture techniques in rat sciatic nerves. Part 1. *Neurosurg* 1985; 17:300–308.
19. Cruz NI, Debs N, Fiol RE. Evaluation of fibrin glue in rat sciatic nerve repair. *Plast Reconst Surg* 1986; 78:369–374.
20. Archibald SJ, Krarup C, Shefner J, Li S-T, Madison RD. A collagen-based nerve conduit for peripheral nerve repair: An electrophysiological study of nerve regeneration in rodents and nonhuman primates. *J Comp Neurol* 1991; 306:385–395.
21. Ashton RJ, Libutti SK, Oz MC, Lontz JF, Lemole GJ, Lemole GM. The effects of laser-assisted fibrinogen bonding on suture material. *J Surg Res* 1992; 53:39–42.
22. Poppas D, Klioze S, Choma T, Schlossberg S. Suture materials used in tissue welding. *Lasers Surg Med Suppl* 1993; 5:62.
23. Menovsky T, Beek JF, van Gemert MJC. CO₂ laser nerve welding: Optimal laser parameters and the use of solders in vitro. *Microsurgery* 1994; 15:44–51.
24. Rosemberg SK. Further clinical experience with CO₂ laser in microsurgical vasovasostomy. *Urology* 1988; 32: 225–227.
25. Okada M, Ikuta H, Shimizu K, Horii H, Tsuji Y, Yoshida M, Nakamura K. Experimental and clinical studies on the laser application in the cardiovascular surgery: Analysis of clinical experience of 112 patients. *Nippon Geka Gakkai Zasshi* 1989; 90:1589–1594.
26. Granberry W, Wilson JN. Experimental comparison of suture materials in repair of small nerves. *J Bone Joint Surg* 1963; 45A:884–889.
27. Edshage S. Peripheral nerve injuries-diagnosis and treatment. *New Engl J Med* 1968; 278:1431–1433.
28. Edshage S. Peripheral nerve suture. Techniques for improved intraneural topography evaluation of some suture materials. *Acta Chir Scand Suppl* 1964; 331:1–140.
29. Mukherjee SR, Douglas DM. An investigation into the value of nylon and terylene as nerve sutures. *Br J Surg* 1951; 39:271–274.
30. Nigst H. Chirurgie der peripheren Nerven. *Z Unfallmed u Berufshr* 1963; 56:19–24.